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Review of Impedance-Based Fault Location Algorithm in Electric Power Transmission Line, using computerized fault recorders.

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Abstract:

Fault location Algorithm is an important task in power system engineer because accurate faults location algorithms on power transmission lines need to be detected and located rapidly, classified correctly and cleared as fast as possible to restore the supply back to the system, so as to avoid possible damages to people, property and environment. In this paper review of impedance- based fault location algorithm in electrical power transmission line, which include, the one-ended impedance algorithm such as (Takagi method, Modified Takagi method, Erikson method, Novosel method) and the two-ended impedance based algorithm such as (synchronized two-ended method and unsynchronized two-ended method).. Fault data availability forms a basic for choosing the most suitable fault location algorithm. The result of this paper shows that the simple reactance method is the simplest and low cost of the entire impedance - based fault location algorithm. The fault resistance and the load current make the algorithm to deteriorate in accuracy. The Takagi method was developed to correct these lapses because of its robustness to load and sensitivity. Source impedance parameters were used by the Modified Takagi and Erikson methods for elimination of any source of errors. The mutual coupling in double-circuit transmission lines and an uncertain value of zero-sequence line impedance are responsible for the inaccuracy of one-ended impedance-based technique. This problem was overcome by two-ended fault location algorithm that used voltage and current measurements captured from both ends of transmission line and are attractive for tracking down the specific position where the fault is to be located. Availability of data is one of the most important factors in selecting the best technique for fault location. Additional equipment needed to be installed for improving the accuracy of fault location algorithm is very useful. This paper will form a basis for choosing an appropriate fault location technique for electrical power transmission network.

Keywords: Transmission Line, Takagi, Modified Takagi, Erikson, Novosel and Impedance-Based methods

INTRODUCTION

Electric power transmission lines have grown rapidly over the past years. This has resulted as increase in number of transmission lines in operation (Ratan and Damir, 2015). Transmission lines are often subjected to electrical faults due to lightning strikes during stormy weather conditions, animal or tree contact with a transmission line, or insulation failure in power system equipment (Catarina, 2005). In most cases, electrical faults manifest in mechanical damage that must be repaired before returning the line to service in the shortest possible times. The service restoration can be accelerated if the accurate of impedance-based fault location algorithm is known, because they are straightforward to implement and with reasonable fault location distance, this way reducing outage time and improving system reliability to the customers.

The primitive method of fault location was to visual inspection of the line which involved patrolling the line by foot or automobile. Sectionalizing the line and energizing it in parts has been used to reduce the length of the line that must be inspected. Surge operated targets, placed on line towers, and tracer currents have been used to further assist in locating faults. These procedures are slow, inaccurate and expensive, and are unsafe during stormy weather conditions. Impedance-based fault location algorithms have been developed for transmission network applications.

In this paper reviews the impedance-based fault location algorithm for transmission lines both one-ended impedance-based fault location algorithms (simple reactance, Takagi, modified Takagi, Eriksson, and Novosel methods) and two-ended impedance-based fault location algorithms (synchronized and unsynchronized methods).

Fault location algorithms using voltage and current waveforms captured by digital relays, or digital fault recorders device at one end of the line are commonly referred to as one-ended algorithms, while those using voltage and current waveforms captured by digital relays, or digital fault recorders at both ends of a transmission line are referred to as two-ended algorithms. Each algorithm has specific input data requirements and makes certain assumptions when computing the distance to a fault. The accurate of fault location algorithm has been of greater interest to electric power utility engineers and researchers.

TYPES OF FAULTS

Faults are generally classified as open and short circuits. In terms of the seriousness of consequences of a fault, short circuits are far greater concern than open circuits.

a. Open Circuit Fault

This is a break or electrical discontinuity in a circuit through which current can normally flow. The term is applied to a transmission line when a voltage difference exists between its end terminals, which are rendered infective by the lack of a complete connecting circuit. These open circuits are also referred to as series faults:

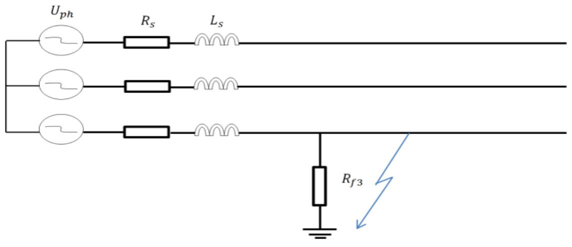

Figure 1: Single phase-to-ground faults

b. Broken conductor fault

Other faults like broken conductor faults are series faults which involve a break in one or two of the three conductors of a three phase power system. Broken conductor faults are usually caused by variable weather condition and climate influences to the power grid.

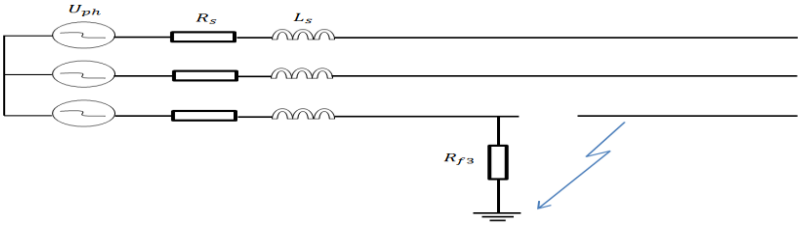

Figure 2: Broken conductor and line-to-ground fault.

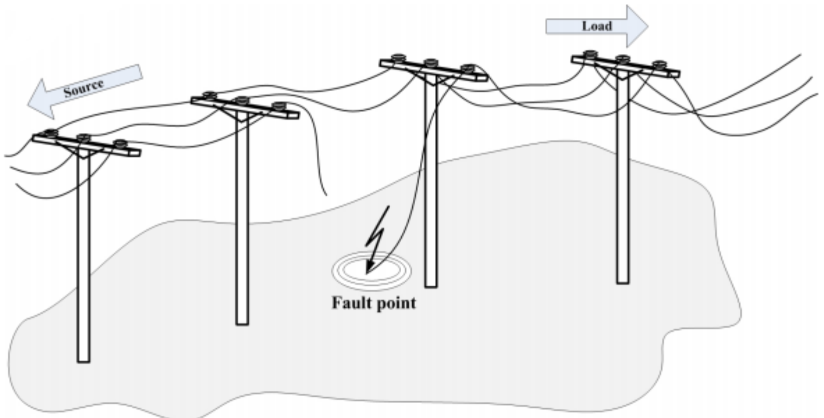

Figure 3: Down Conductor fault on overhead line

Strong wind may also create Aeolic harmonics vibration on power transmission lines; these vibrations are associated with great tension on the conductors, which can lead to broken conductors. This phenomenon, where the conductors come in contact with one another during strong wind or other external forces, is called conductor clashing.

Causes of Open Circuit Fault

Open circuit faults in transmission line are caused as a result of the following:

i. Wire-cut
ii. Jumper-cut
iii. J & P fuses Rupture
iv. Malfunctioning of circuit breaker in one or more phases

c. Short Circuit Fault

This is defined as a bridge or connection between two points of a circuit, particularly across a source of electrical energy, by a conducting path of low resistance. Short circuit is capable of causing permanent flashover in transmission line equipment if allowed to persist even for a brief period. Hence, it is considered critical and the affected path must be removed or isolated from the entire network as fast as possible. A typical transmission short circuit includes: phase-to-phase, double-phase-to-earth, and three-phase-to-ground short circuit faults.

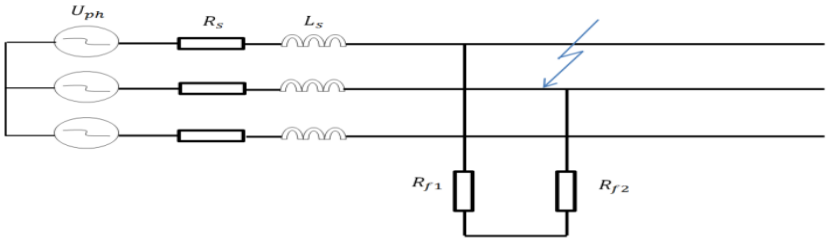

Figure 4: Phase-to-Phase fault

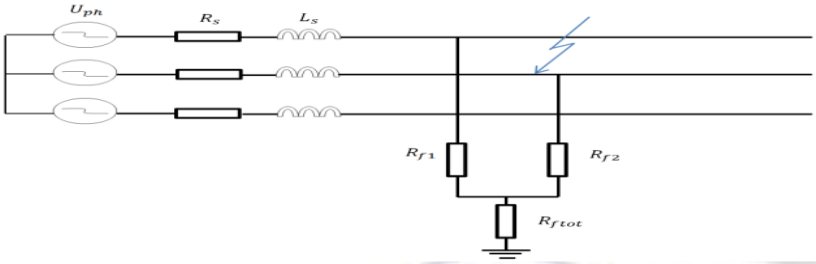

Figure 5: Double phase to ground fault

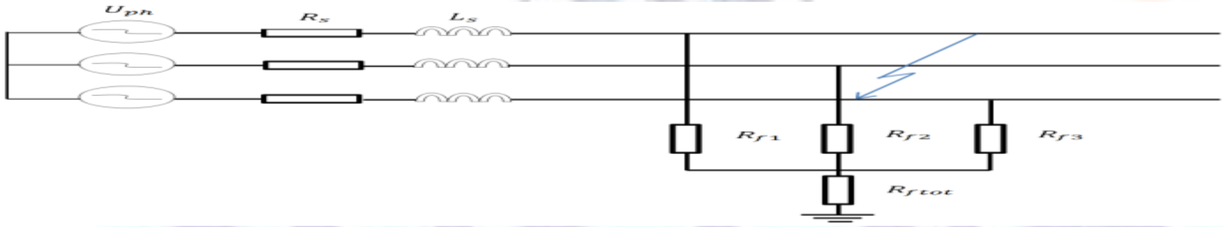

Figure 6: Three phases to ground fault

Causes of Short Circuit Faults

Short circuit faults in power transmission lines are primarily caused by insulation failure of transmission lines or equipment emanating from various internal (switching surges and deterioration of the line insulation) and external (lightning surges, bird, pollution, mechanical damage by public).

MATERIALS AND METHOD

This Section reviews the one-ended and two-ended impedance based fault location algorithms that are commonly used to locate faults in a transmission network. The goals are to define the input data requirement of each method and identify the different factors that affect the accuracy of location estimates. Therefore, fault location methods are developed in many different ways. The fundamental requirement of fault location methods are accuracy and reliability.

A. One-end Impedance-Based Fault Location algorithms

In this algorithms estimate a distance to a fault with the use of voltages and currents data acquired at one side parameter of transmission line. (Ahmed , Akshay , Ankit and Deepika, 2007) as illustrated in Fig. 1.below. The advantages of using one-ended algorithms, because they are straightforward to implement, with reasonable fault location estimates. Hence communication channel are not required only microprocessor-based numerical relay are placed at the end of a transmission line. (Swagata D and Anish G, 2014). However, this Algorithm is subject to several sources of error, such as the reactance effect, the line shunt capacitance, and the fault resistance value (Dine, Sayah and Bouthiba, 2012).

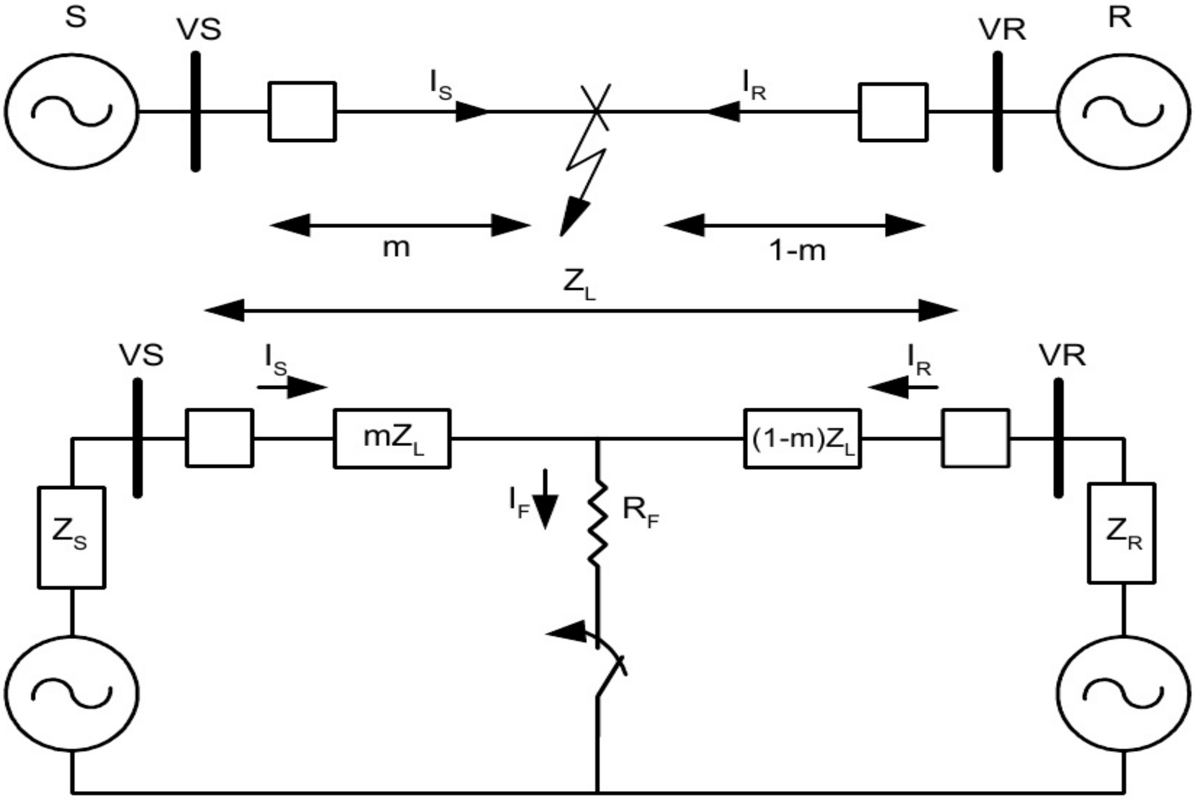

Figure 7: One-line and equivalent circuit for a fault on a transmission line

Consider the two-terminal transmission network shown in Fig. 1. The transmission line is homogeneous.

Z_{L1} is total positive sequence impedance between terminals S and R respectively.

Z_S and Z_R are source impedances at terminals S and R respectively.

R_F is fault resistance

M at a distance per unit from terminal S,

I_F is the total fault current.

V_S and I_S are the voltage and current phasors recorded at terminal S during the fault respectively.

V_R and I_R are the voltage and current phasors recorded at terminal R during the fault respectively.

Therefore, these measurements are available at both ends of the line, one-ended methods use the voltage and current captured at terminal S or at terminal R. Applying Kirchhoff's laws, the voltage drop from terminal S can be expressed as

$$V_S = MZ_{L1}I_S + R_F\, I_F \qquad (1)$$

Where, V_S and I_S are depends on the fault type and dividing equation (1) all throughout by I_S.

Zapp is apparent impedance to the fault measured from terminal S, can be calculated as;

$$Z_{app} = \frac{V_S}{I_S} = MZ_{L1} + R_F\left(\frac{I_F}{I_S}\right) \tag{2}$$

Equation 2 is the fundamental equation that governs one-ended impedance-based fault location algorithms. Unfortunately, because measurements from only one end of the line are used, and there is three unknowns variable namely, m, R_F, and I_F.

B. Simple Reactance Algorithm

This algorithm, estimates the reactance to a fault in order to eliminate fault resistance (R_F) from the fault location calculation. The method is computationally simple and requires minimum data for fault location. However, the accuracy of the distance to fault estimates is severely affected when I_F and I_G is not in phase. The phase angle mismatch can be attributed to the system load present at the time of the fault. While in non-homogeneous system, currents I_S and I_R do not have the same phase angle. Because I_F is the summation of I_S and I_R, the phase angle of I_F is also not equal to that of I_S. As a result, R_F (I_F /I_S) is a complex number.

The distance to a fault is given by

$$m = \frac{imag\left(\frac{V_S}{I_S}\right)}{imag(Z_{L1})} \tag{3}$$

C. Takagi algorithm

This algorithm improves the performance of the simple reactance method, which required pre-fault and fault data to reducing the effect of fault resistance. The Takagi algorithm introduces superposition current$(\mathrm{I_{Sup}})$ to eliminate the effect of power flow. This method assume constant current load model (Takagi, Yamakoshi, Yamaura, Kondow, and Matsushima, 1982).

$$V_S = M\ .\ Z_{L1}\ .\ I_S +\ R_F\ . \tag{4}$$

Use superposition current $(\mathrm{I_{Sup}})$ to find a term in phase with $\mathrm{I_F}$

$\mathrm{I_{Sup}} = \mathrm{I} - \mathrm{I_{pre}}$

Where, $\mathrm{I_F}$= fault current

$\mathrm{I_{pre}}$ = pre-fault current

$\mathrm{R_F} = \text{fault resistance}$

$\mathrm{I_{Sup}} = \text{superposition current}$

Z_{L1} is total positive sequence impedance

V_S and I_S are the phasors voltage and current

M = distance per unit

In a homogenous system, if complex number $\mathrm{I_S}$ and $\mathrm{I^x_{Sup}}$ have the same angle as $(\mathrm{R_F})$, therefore multiplication of $(\mathrm{I^x_{Sup}})$ take the imaginary part of the equation and eliminate $\mathrm{I_F}$

$$m = \frac{V_S}{I^x_{Sup}} = m\, .\, imag\big(\, Z_{L1}\, .\, I_S\, .\, I^x_{Sup}\big) + imag\big(\, R_F\ .\ I_F\ .\ I^x_{Sup}\big) \tag{5}$$

$$m = \frac{imag(V_S \, x \, I_{Sup}^{x})}{imag(\, Z_{1L} \, x \, I_S \, x \;\, I_{Sup}^{x}\,)} \qquad (6)$$

The key to the success of the Takagi method is that the angle of I_S is the same as the angle of I_F.

For an ideal homogeneous system, these angles are identical. As the angle between I_S and I_F increases, the error in the fault location estimate increases.

D. Modified Takagi algorithm

Modified Takagi method eliminates the need for pre fault current data and uses the zero sequence current (I_0) to account for system load during single phase to ground fault, instead of the superposition current. The zero-sequence Takagi method, which is suitable for single phase to ground faults, has an advantage that does not require pre fault current measurements (Zimmerman and Costello, 2005). The distance to fault is calculated from the following expression;

$$m = \frac{imag(V_S \, x \, 3I_0^{x})}{imag(\, Z_{L1} \, x \, I_S \, x \;\, 3I_0^{x}\,)} \qquad (7)$$

The algorithm is developed with the assumption that the zero sequence system is homogeneous.

E. Eriksson Algorithm

This algorithm uses source impedance parameters to overcome any reactance error caused by fault resistance and load also this algorithm reducing the effect of fault resistance (Eriksson, Saha, and Rockefeller, 1985).

To determine the distance to a fault, the current distribution factor ds is directly substituted to give

$$V_s = MZ_{1L}I_S + R_F\left(\frac{Z_{S1} + Z_{L1} + Z_{R1}}{(1 - M)Z_{L1} + Z_{R1}}\right)\Delta I_S \qquad (8)$$

Simplifying and rearranging the terms result in the following expression:

$$M^2 - mK_1 + K_2 - K_3R_F = 0 \qquad (9)$$

Where,

K_1, K_2, and K_3 are constant complex multiplications of voltage, current, line impedance, and source impedances and are defined as follows:

$$K_1 = a + jb = 1 + \frac{Z_{R1}}{Z_{L1}} + \left(\frac{V_s}{Z_{L1} + Z_{S1}}\right) \qquad (10)$$

$$K_2 = C + jd = \frac{V_s}{Z_{L1} + Z_S} + \left(1 + \frac{Z_{R1}}{Z_{L1}}\right) \qquad (11)$$

$$K_3 = e + jf = \frac{\Delta I_G}{Z_{L1} + Z_S} + \left(1 + \frac{Z_{R1} + Z_{S1}}{Z_{L1}}\right) \qquad (12)$$

Therefore, adequate separation into real and imaginary parts, hence the solution of the distance to fault using the following quadratic equation

$$M = \frac{a - \frac{eb}{f} \pm \sqrt{\left(a - \frac{eb}{f}\right)^2 - 4\left(c - \frac{eb}{f}\right)}}{2} \qquad (13)$$

Where, m can take two possible values. Since the fault location estimate must be less that the total line length, the value of m that lies between 0 and 1 per unit should be chosen for fault location accuracy.

Fault resistance can then be calculated as:

$$R_F = \frac{d - mb}{f} \tag{14}$$

F. Novosel Algorithm

This approach is a modified version of the Eriksson and it is used for locating faults on a short radial transmission line (Novosel, Hart, Hu, and Myllymaki, 1998) All loads served by the transmission lines and are lumped at the end of the feeder by estimating the load impedance from the pre fault voltage and current as

$$Z_{load} = R + jX = \frac{V_{S1}R_2}{I_{S1R_2}} - Z_{L1} \tag{15}$$

The per-unit distance to the fault can be obtained by using the quadratic equation in (13), where the constants are defined as:

$$K_1 = a + jb = 1 + \frac{Z_{load}}{Z_{L1}} + \left(\frac{V_G}{Z_{L1} + Z_{S1}}\right) \tag{16}$$

$$K_2 = C + jd = \frac{V_G}{Z_{L1} + Z_S} + \left(1 + \frac{Z_{load}}{Z_{L1}}\right) \tag{17}$$

$$K_3 = e + jf = \frac{\Delta I_G}{Z_{L1} + Z_S} + \left(1 + \frac{Z_{load} + Z_{S1}}{Z_{L1}}\right) \tag{18}$$

The value of m which lies between 0 and 1 per-unit is chosen as the location estimate. The Novosal Algorithm is robust to any reactance error due to fault resistance and load.

G. Two-end Impedance-Based Fault Location algorithms

Two-ended fault location algorithm is similar to the one-terminal algorithm (Akshay, Ankit and Deepika, 2007). But the algorithms can improve the accuracy of fault location measurements by using voltage and current signals or data captured at both ends of a transmission line to estimate the fault location. This algorithm cancels the effect of fault resistance and other factors which affect the accuracy of fault location. Therefore, performance of the two-end algorithm is generally superior in comparison to the one-end algorithm (Izykowski, Molag, Rosolowski, and Saha, 2006). Two-end fault location algorithms are further classified as follows: synchronized and unsynchronized measurement.

H. **Synchronized Two-ended Method**: This method assumes that measurements from both ends of a transmission line are synchronized to a common time reference using Global Positioning Satellite (GPS). Any one of the three symmetrical components can be used for fault location computation.

I. **Unsynchronized Two- ended Method:** This method use relay devices to captured waveform at both ends of a transmission line may not be synchronized with each other. The main advantage of such methods is the lower cost of implementation, since there is no need to use global positioning system (GPS) or other devices to provide a common time base for the measurement instruments of the two ends. (Dine, Sayah and Bouthiba, 2012). Alternatively, relays may detect the fault at slightly different time instants. The communication channel which transfers data from one relay to the others, can also introduce a phase shift. Impedance-based methods are popular among electric power utilities because they are simple and economical compared to those based on the traveling wave and high frequency component.

We don't need to recognize the type of fault in order to calculate the location of the fault. Therefore using negative-sequence voltage obtained from both side of its symmetrical components at the fault point, the effects of pre-fault power flow and fault resistance are eliminated. Unlike one-end methods, negative sequence requires source impedance to perform fault location estimation.

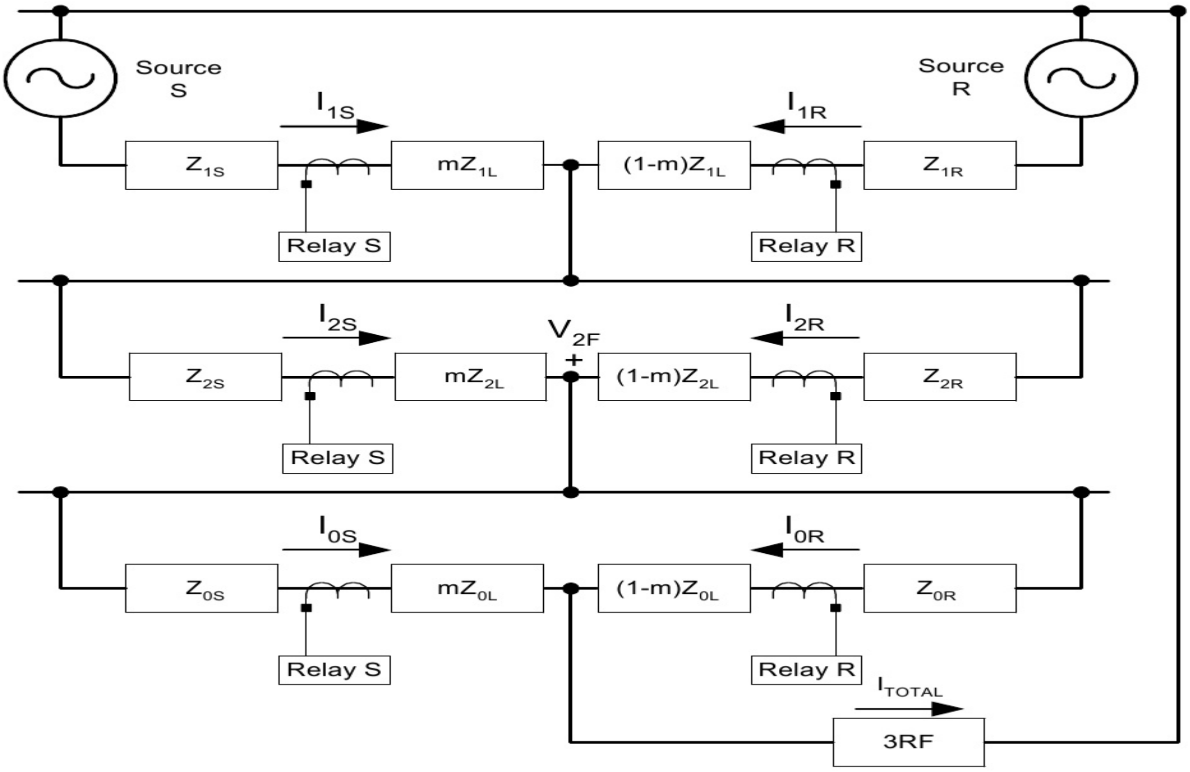

Figure 8: connection of sequence networks for a single line-to-ground fault at m

The general formula of the algorithm uses calculation from both sides of the transmission line with elimination of the fault voltage (V_F).

At relay S-side:

$$V_F = -I_{S2}\ x\ (Z_{S2} + MZ_{L2}) \qquad (19)$$

At relay R-side:

$$V_F = -I_{R2}\ x\ (Z_{R2} + (1 - M)Z_{L2}) \qquad (20)$$

By eliminating fault voltage, from equation (19) and (20) and rearrange the resulting expression follows:

$$(I_{R2}) = I_{s2}\ x\ \frac{(Z_{S2} +\ MZ_{L2})}{[(Z_{R2} + (1 - M\ )\ x\ Z_{L2}]} \qquad (21)$$

To avoid alignment of Relay S and R data sets, take the magnitude of both sides of Equation 21 as follows:

$$(I_{R2}) = I_{s2}\ x\ \frac{(Z_{S2} +\ MZ_{L2})}{[(Z_{R2} + (1 - M\ )\ x\ Z_{L2}]} \qquad (22)$$

Equation 22 is then simplified to Equation 23 below.

$$(I_{R2}) = \frac{[(I_{S2}\ x\ Z_{S2})] + M\ x\ (I_{S2}\ x\ Z_{L2})}{[(Z_{R2}\ x\ Z_{L2}) - M\ x\ Z_{L2}]} \qquad (23)$$

To further simply Equation (23), define the following variables:

$$I_{S2}\ x\ Z_{S2} = a + jb$$

$$I_{S2}\ x\ Z_{L2} = c + jd$$

$$Z_{R2}\ x\ Z_{L2} = e + jf$$

$$Z_{L2}\ = g + jh$$

Substituting these variables into Equation (23) we have:

$$(I_{R2}) = \frac{[(a + jb\ )] + M\ x\ (c + jd\ )}{[(\ e + jf\ ) - M\ x\ (g + jh)]} \qquad (24)$$

Taking the square of both terms of Equation (24), expanding and rearranging terms produces a quadratic equation of the form:

$$A = M^2 + B\ x\ M + C = 0 \qquad (25)$$

Equation (25) is solved for distance to fault using quadratic solution model. The coefficients Equation (25) are given below.

$$\begin{aligned} A &= (I_{R2})^2 x\ (g^2 + h^2) -\ \ (c^2 + d^2) \\ B &= -2\ x\ (I_{R2})^2 x\ (e\ x\ g + f x\ h) - 2\ x\ (a\ x\ c + b\ x\ d\ ) \\ C &= (I_{R2})^2 x\ (e^2 + f^2) -\ \ (a^2 + b^2) \end{aligned} \qquad (26)$$

IV. SOURCES OF ERROR IN IMPEDANCE-BASED FAULT LOCATION ALGORITHMS

a. The accuracy of the fault location estimates depends on the accuracy of the input parameters.

b. Accurate estimations of the voltage and current phasors depend on the transducers and inherent errors are associated with the measurement.

c. Effect of dc component in currents should be considered while estimating fundamental frequency component of currents

d. Line parameters depend on different factors including the resistivity of the soil, the ambient temperature and the transposition of the line. Accuracy of any fault location algorithm depends on the line parameters and should be known as accurately as possible within practical limits. Several other issues, which affect the accuracy of the algorithm are:

e. Combined effect of the load current and fault resistance,

f. Effect of shunt capacitance for long lines,

g. Zero-sequence mutual coupling between parallel lines and

h. Correct fault type identification,

V. CONCLUSION

An overview of impedance-based fault location algorithm in electrical power transmission system has been carried out. Impedance based algorithm using voltage and current phasors from installed transducers such as numerical relays and fault recorders. Under this algorithm, voltage and current phasors may be taken from both terminals or from a single terminal of a transmission line.

Two-end impedance based fault location algorithm provides more accurate results compared to one-end algorithm because the algorithm is not affected by fault resistance and reactance. Phasor voltage and current can be collected from two-end of a transmission line by synchronized data.

Impedance based technique is widely used because of its simplicity and low cost. If the fault is underground, fault resistance will be small and it does not affect the precision of the fault location. In case of the grounded fault, fault resistance will be high and it will affect the fault location. Fault distance is calculated by measuring the reactance at one end of the line.

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